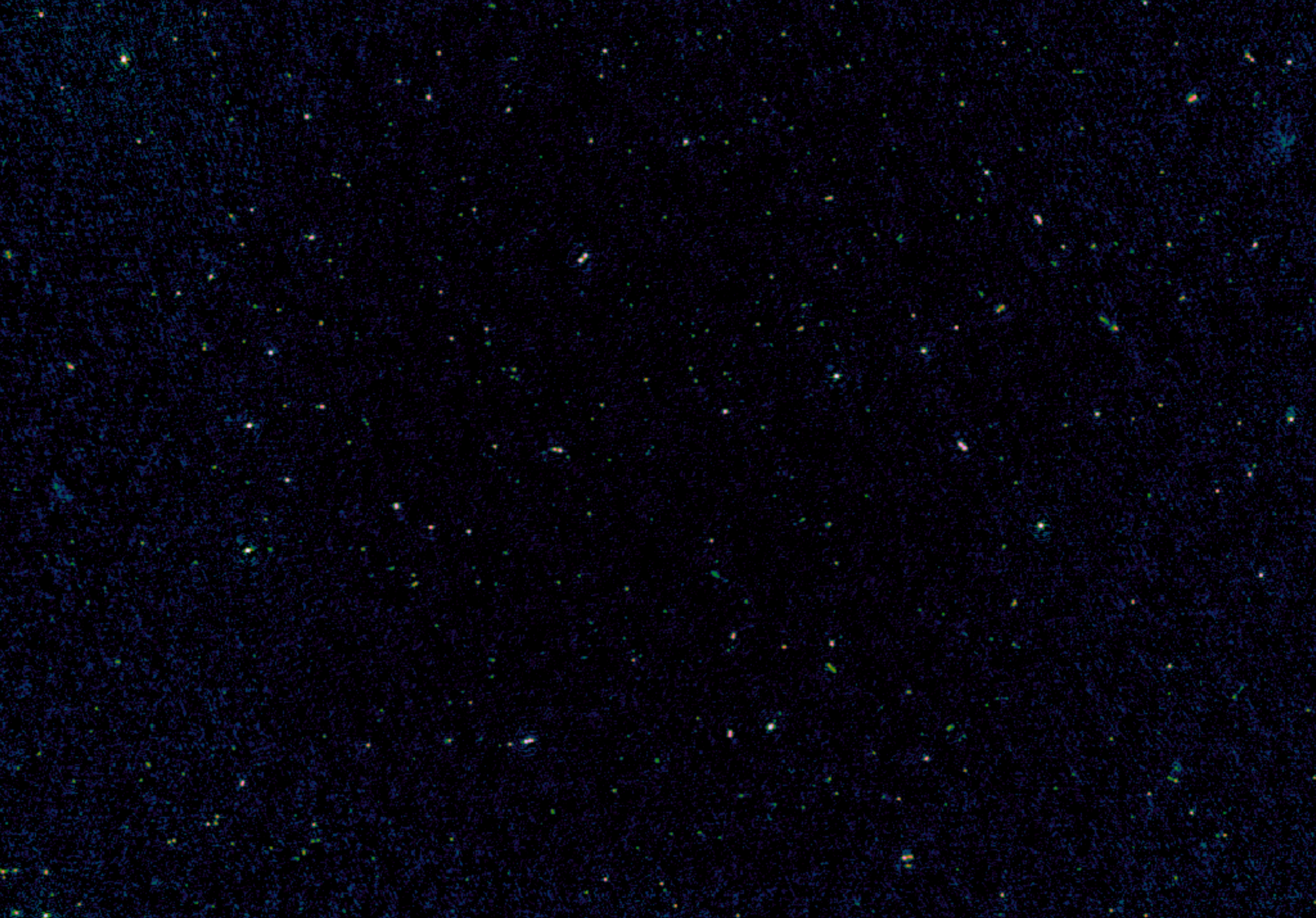
The spectral index-flux density relation for extragalactic radio sources selected at meter and decametre wavelengths

Pratik Dabhade
(IAC, Spain)

18th - 22nd March 2024
Cosmology in the Alps conference

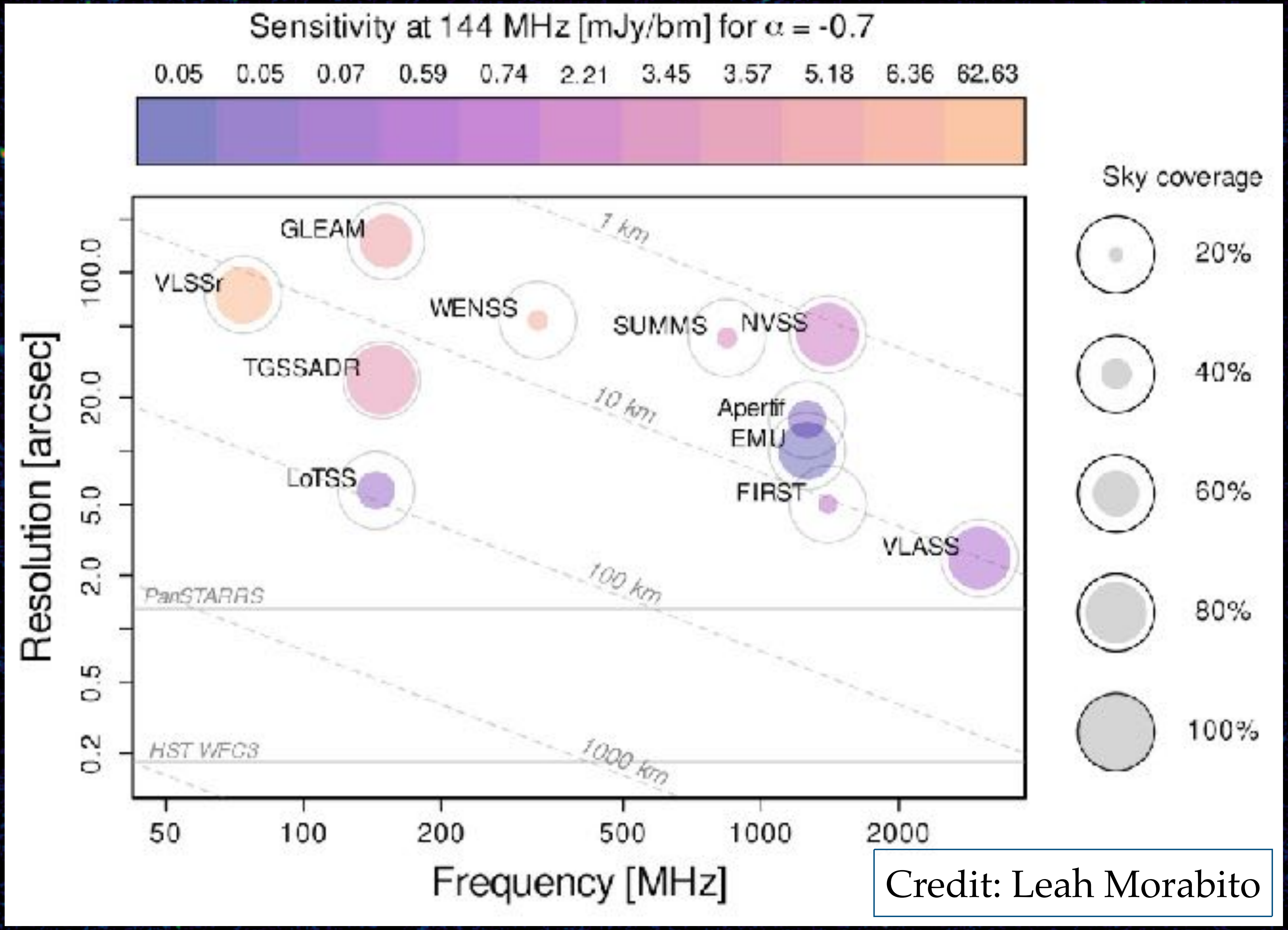
Supported by SWISS NATIONAL SCIENCE FOUNDATION

Typical Radio sky



Typical Radio sky

- Radio surveys provide a wealth of data.
- Gain the ability to study populations and their distribution.
- Determine if results applicable to a population as a whole.
- Can be driving force behind of many new radio telescopes!

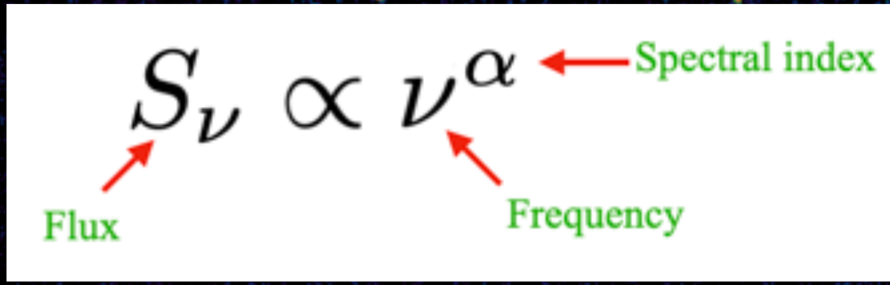


Credit: Leah Morabito

However, they are more useful with optical data!

STUDYING RADIO SOURCE POPULATION

- **Any systematic variation of spectral index with flux density can possibly be used to constrain models of cosmological evolution of extragalactic radio sources (Dagkesamanskii 1970; Laing & Peacock 1980; Condon 1984; Kulkarni et al. 1990; Calistro Rivera et al. 2017).**
- **In absence of all-sky deep spectroscopic surveys, such studies allows infer distant sources and examine the evolution.**



Steep: < -0.5

Flat: > -0.5

Steeper spectral index -> Older sources ?

Fainter radio sources -> Distant sources ?

Flatter spectral index -> younger sources ?

Source Population and Cosmological Evolution: Any systematic variation in spectral properties with flux density suggests a change in the mix of source populations at different flux levels. This also has implications for the cosmological evolution of radio sources of different powers, suggesting that the relative contributions of different types of radio galaxies (e.g., Fanaroff-Riley types I and II, Starbursts) might change over cosmic time. Models must account for this evolution, in order to realistically describe the cosmic history of AGN radio activity in the universe.

Astron. Astrophys. 113, 150–154 (1982)

ASTRONOMY AND ASTROPHYSICS

Spectral Index – Flux Density Relation for Extragalactic Radio Sources Found in Metre-wavelength Surveys

Gopal-Krishna* and H. Steppe

Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-5300 Bonn 1, Federal Republic of

Received May 13, 1981; accepted May 24, 1982

$$S_\nu \propto \nu^\alpha$$

Spectral index

Flux

Frequency

2700 MHz

$$\alpha_{327}^{2700}$$

327 MHz

Astron. Astrophys. 113, 150–154 (1982)

ASTRONOMY

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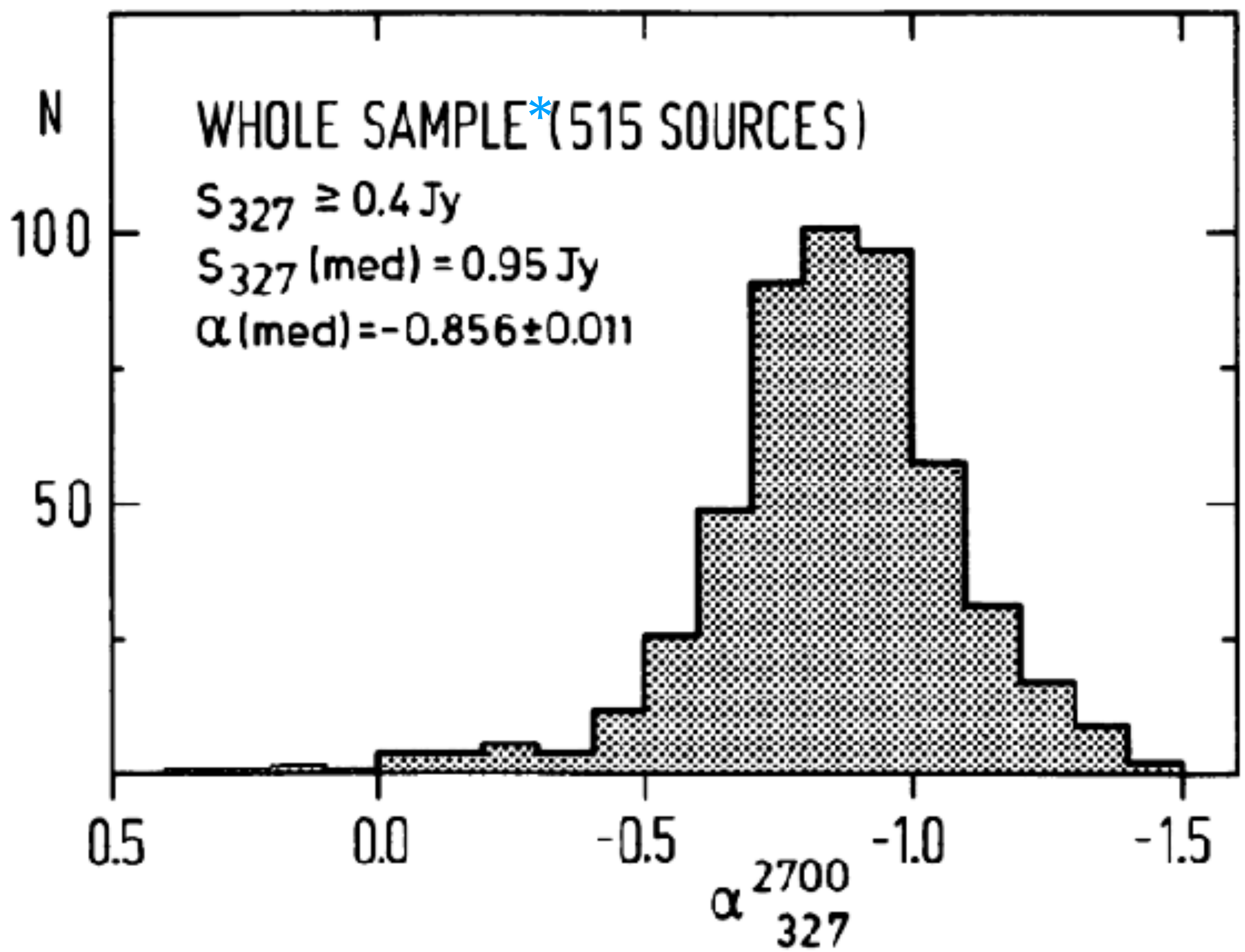

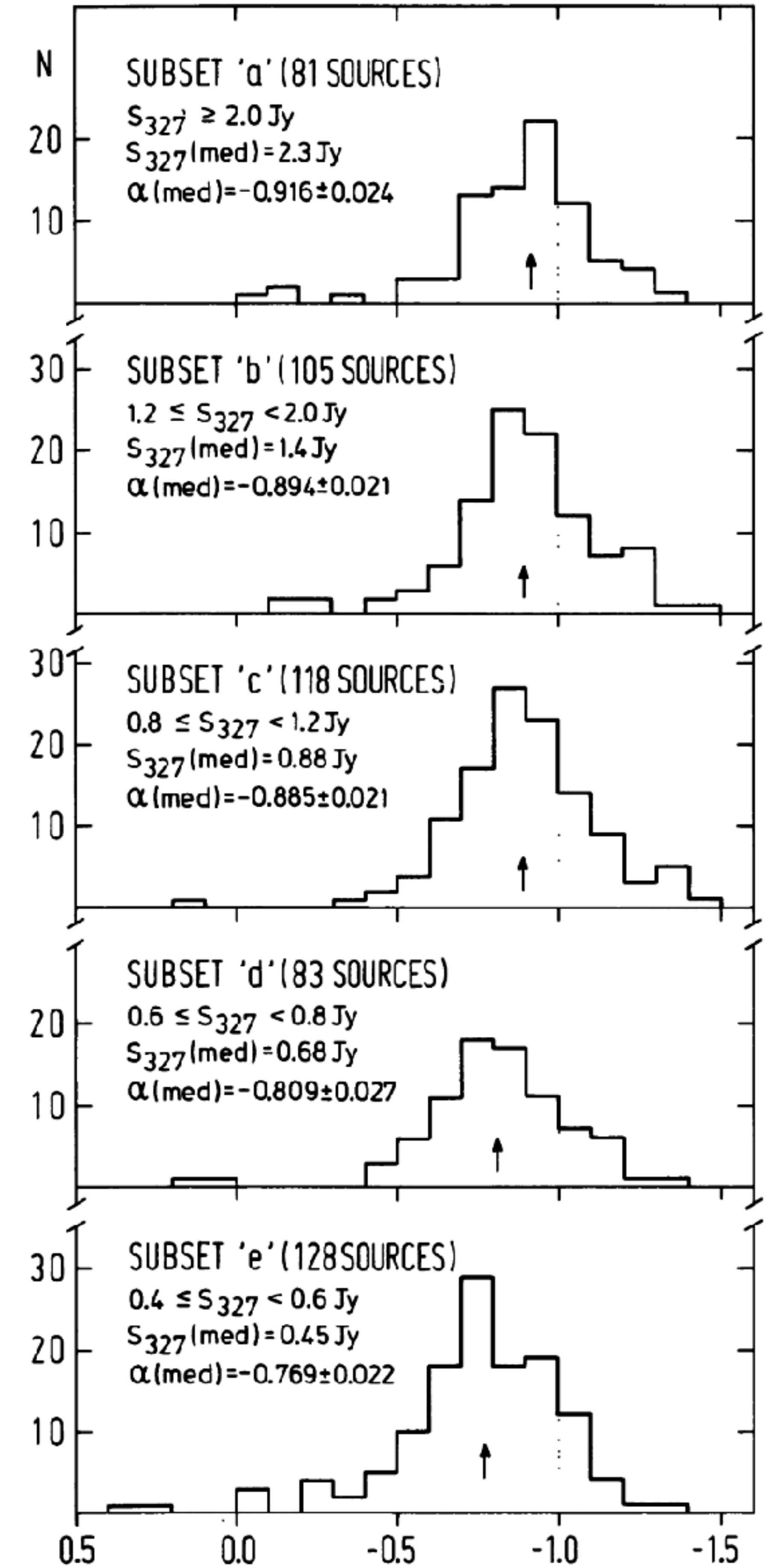

* Sample from Ooty Occultation survey @ 327 MHz (Joshi & Singal 1980)

Astron. Astrophys. 113, 150–154 (1982)

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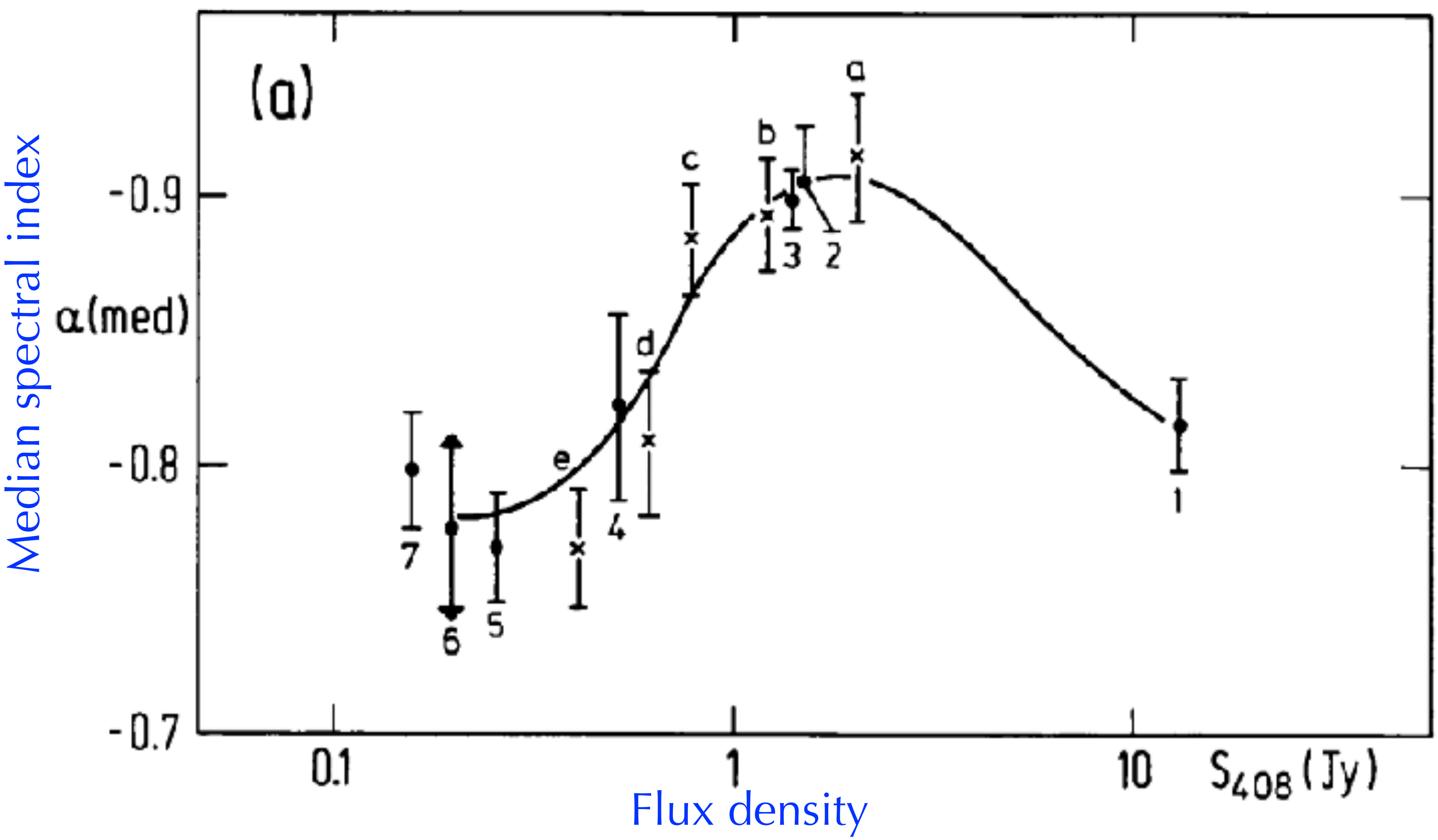
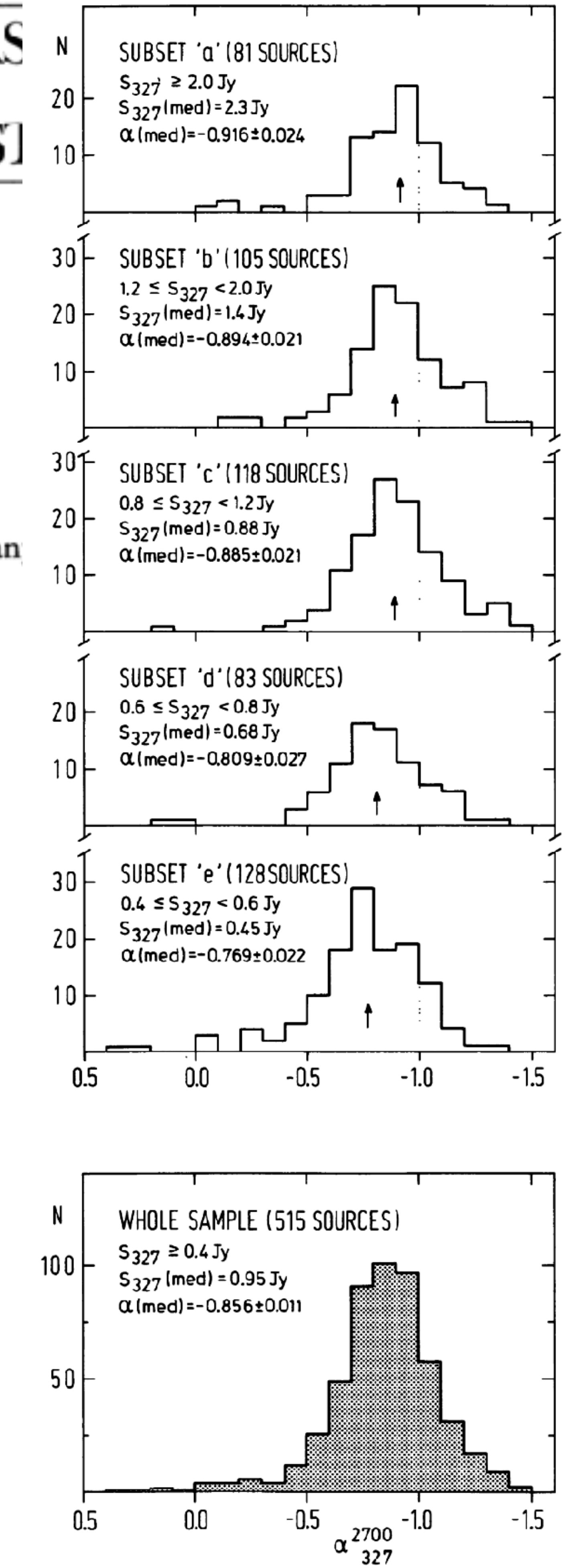




2nd paper further confirming the relation with more complete samples (408 MHz)

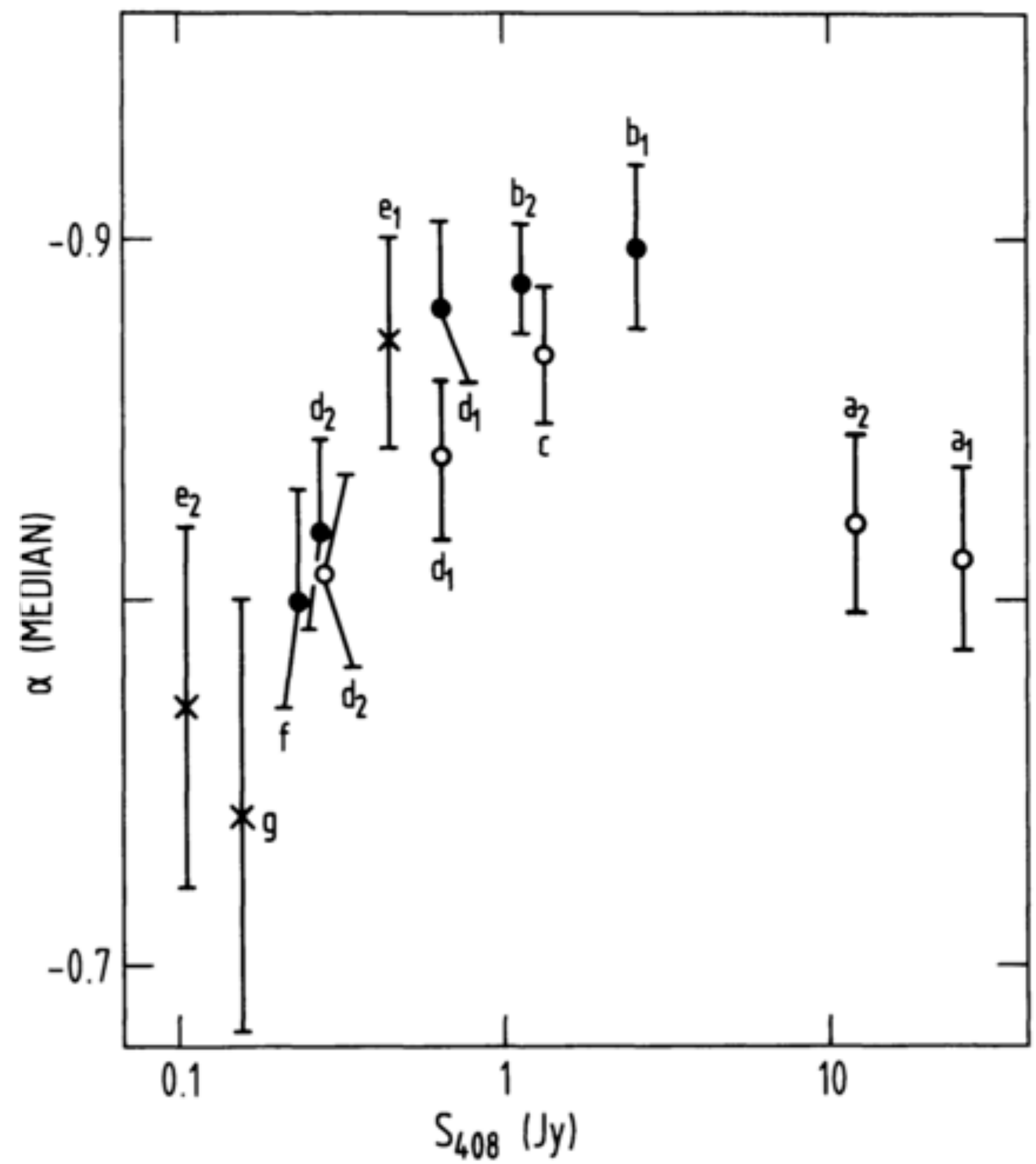
The spectral index/flux density relation for extragalactic radio sources found in metre-wavelength surveys: an updating

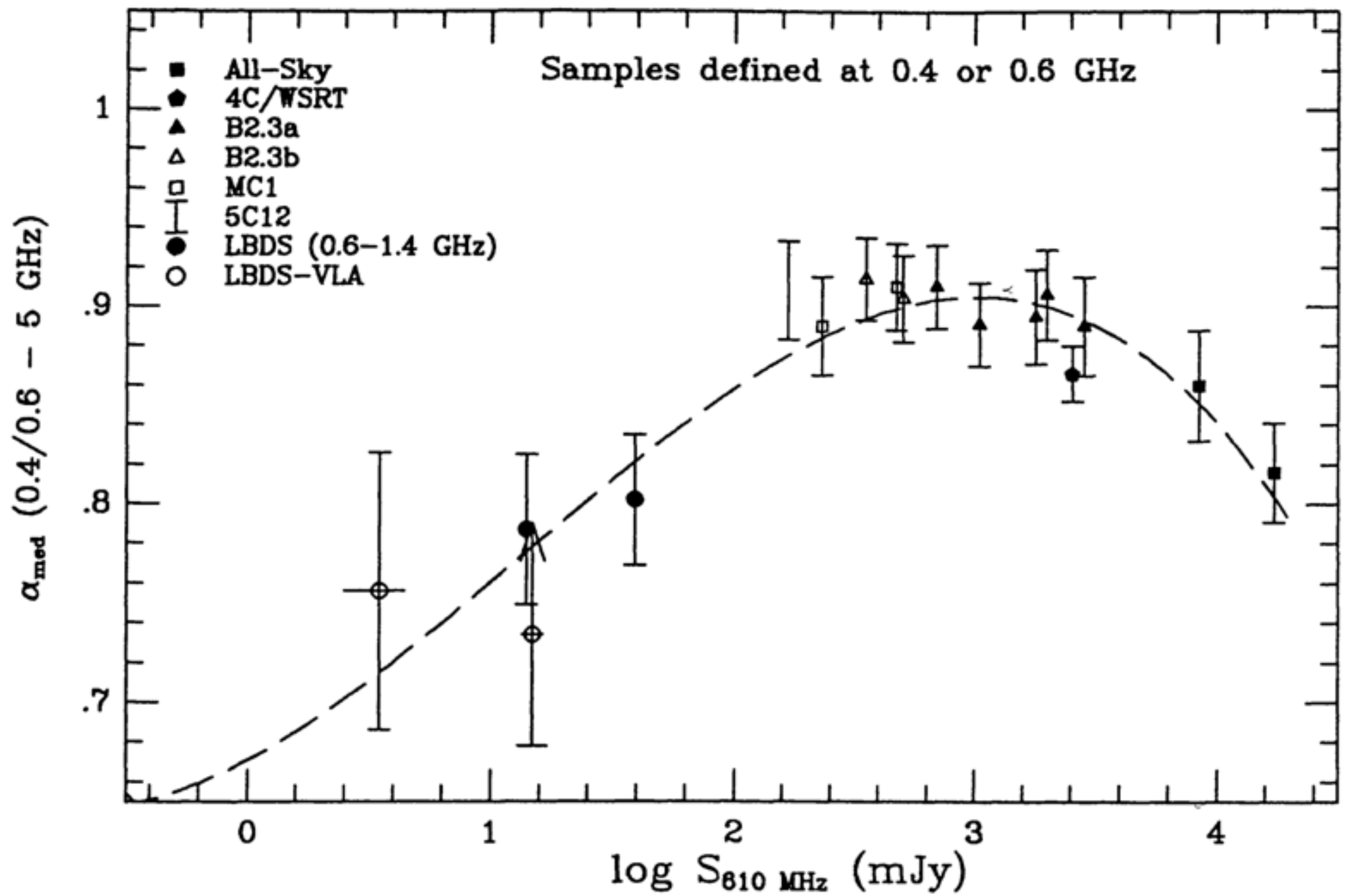
H. Steppe[1] **and Gopal-Krishna**[2]

[1] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-5300 Bonn 1, Federal Republic of Germany
[2] Tata Institute of Fundamental Research, Radio Astronomy Center, I.I. Sc. Campus, P.O. Box 1234, Bangalore-560 012, India

Received December 21, 1983; accepted January 11, 1984

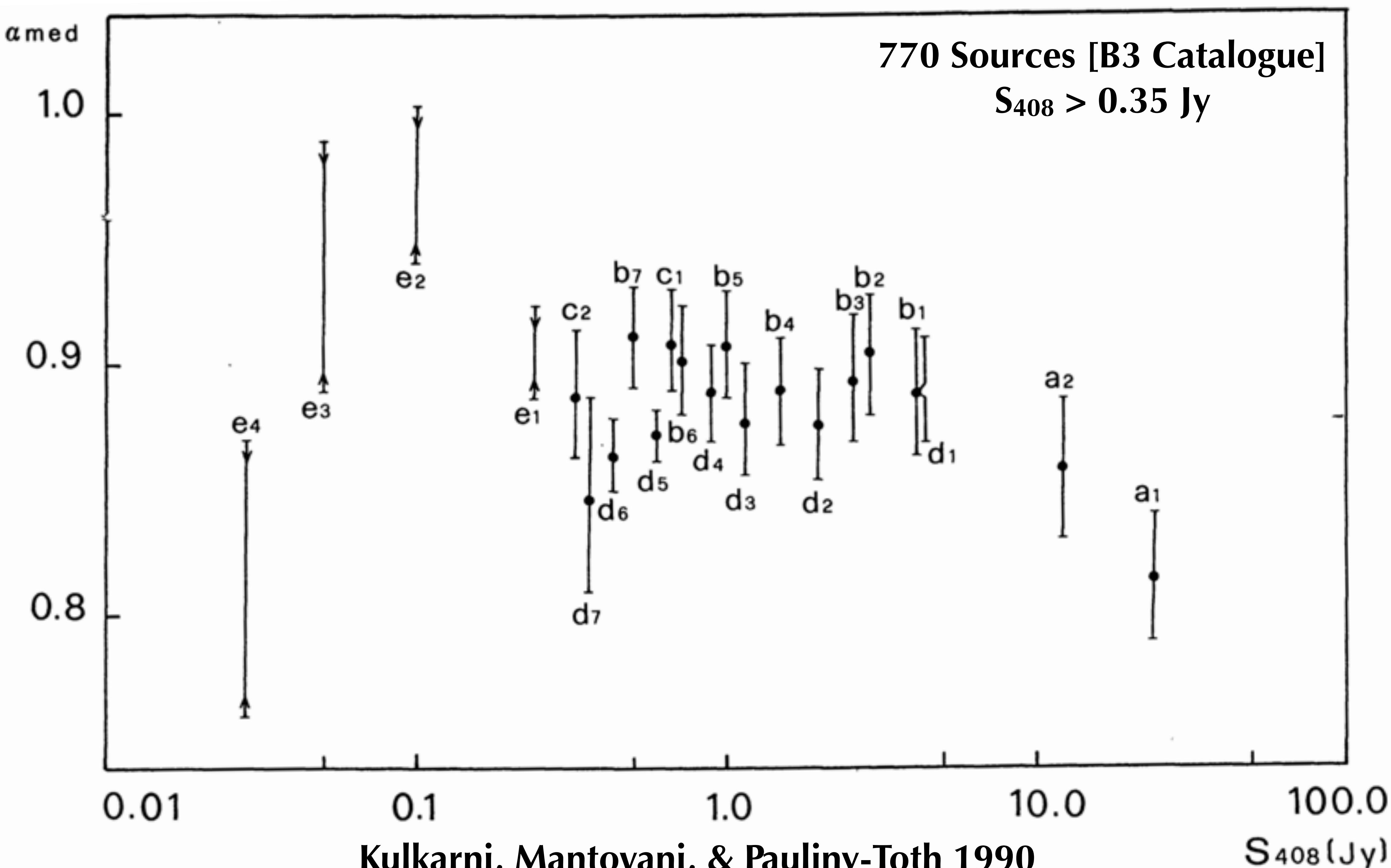
Sample[#]	Parent catalogue	Selection frequency (MHz)	Number of sources	Median flux density[+] (Jy)	α(Median)[ρ]	Fraction of sources with α > −0.5
a1	'All-sky' sample	408	74	24.5	$\alpha_{408}^{2695/2700}=-0.811\pm0.025$	4.1±2.3
a2	'All-sky' sample	408	85	11.7	$\alpha_{408}^{2695/2700}=-0.820\pm0.025$	7.0±2.7
b1	B2.3	408	81	2.7	$\alpha_{408}^{4850}=-0.898\pm0.023$	9.9±3.3
b2	B2.3	408	239	1.2	$\alpha_{408}^{4850}=-0.889\pm0.015$	7.1±1.7
c	MC2/MC3	408	133	1.4	$\alpha_{408}^{2695}=-0.867\pm0.019$	5.3±1.9
d1	MC1	408	117	0.68	$\alpha_{408}^{2695}=-0.839\pm0.022$	5.1±2.1
					$\alpha_{408}^{4750}=-0.882\pm0.022$	6.0±2.2
d2	MC1	408	95	0.29	$\alpha_{408}^{2695}=-0.808\pm0.027$	5.3±2.3
					$\alpha_{408}^{4750}=-0.818\pm0.026$	4.2±2.1
e1	5C12	408	49	0.47	$\alpha_{408}^{1407/1415}=-0.87\pm0.03$	8.2±3.9
e2	5C12	408	48	0.11	$\alpha_{408}^{1407/1415}=-0.77\pm0.05$	18.8±5.6
f	5C6	408	43	0.25	$\alpha_{408}^{4850}=-0.80\pm0.03$	ρρ
g	WSRT survey	610	44	0.16	$\alpha_{610}^{1415}=-0.74\pm0.06$	ρρ





Further confirmed by Windhorst et al. (1990), Ficarra et al. (1985) & Vigotti et al. (1989)

Contradictory result showing constant spectral index at lower flux densities..



Kulkarni, Mantovani, & Pauliny-Toth 1990

Does the S-alpha relation shows a flattening below S_{400} ~ 1 Jy ?

A&A 675, L3 (2023)
https://doi.org/10.1051/0004-6361/202346593

Letter to the Editor

The spectral index-flux density relation for extragalactic radio sources selected at metre and decametre wavelengths

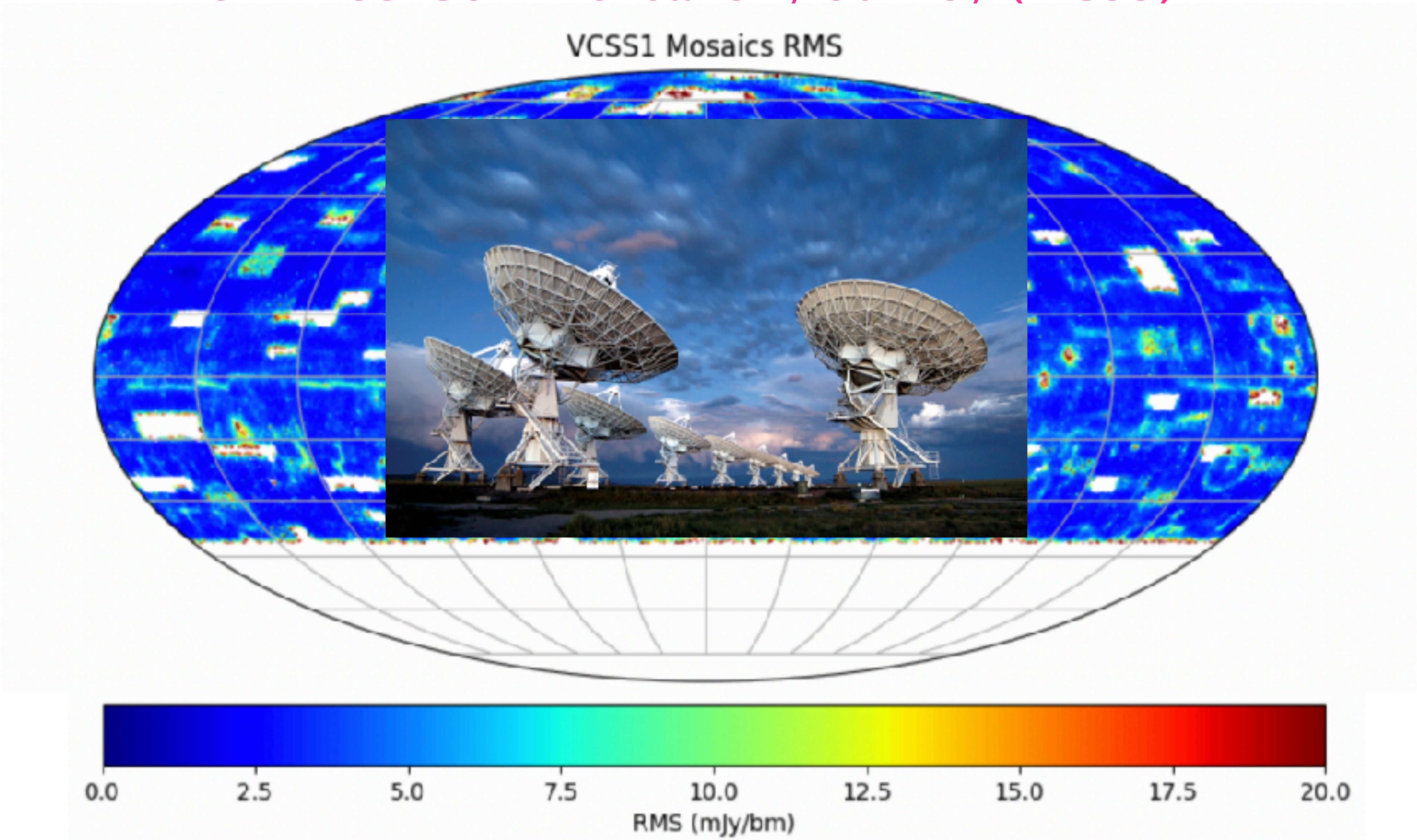
Pratik Dabhade[1,2] and Gopal-Krishna[3]

Sensitive large sky area low frequency radio surveys

-With negligible missing flux
-Coarser angular resolution

I

The VLASS Commensal Sky Survey (VCSS)

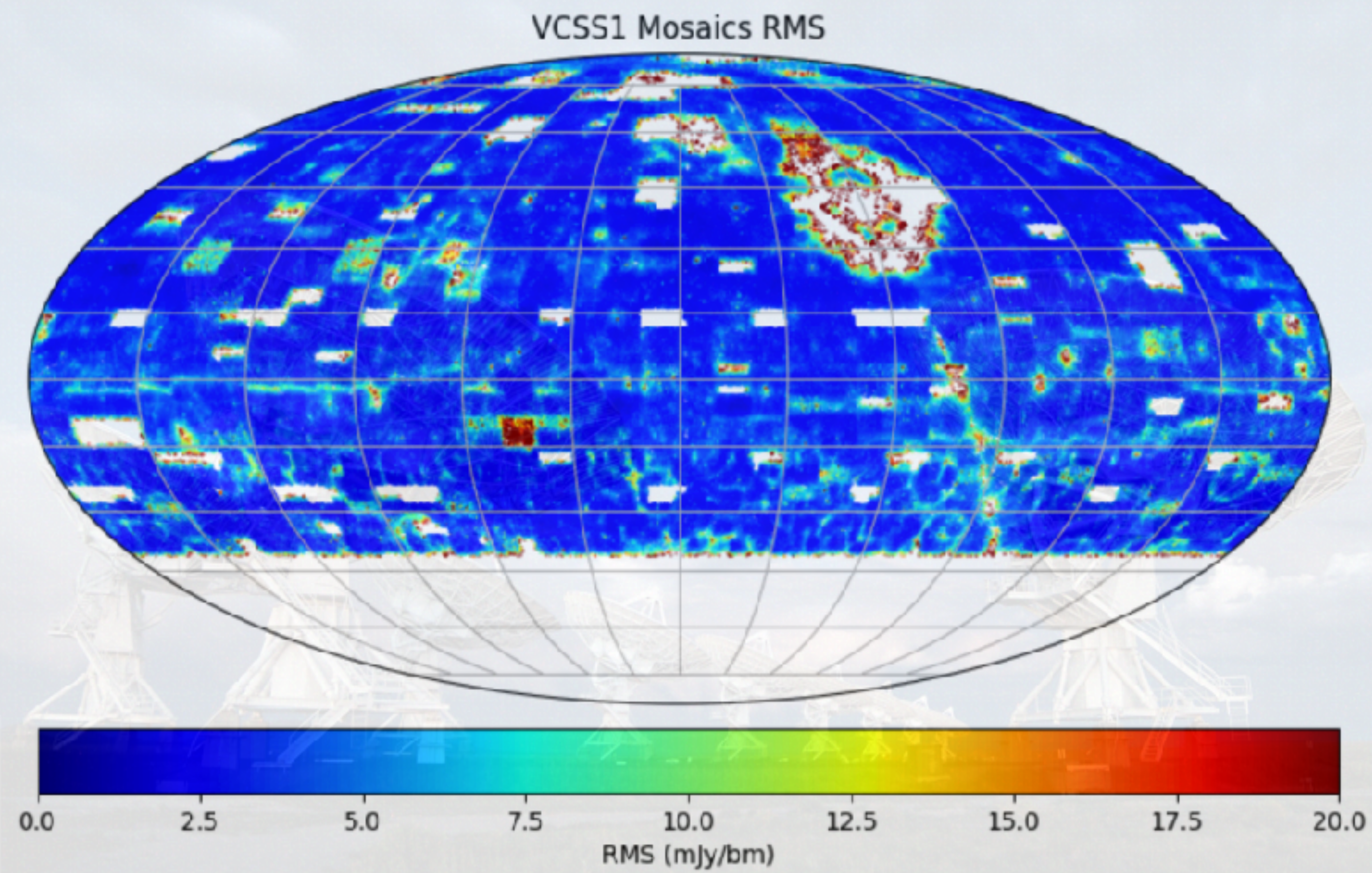


Instrument: -> VLA Low-band Ionosphere and Transient Experiment (VLITE)

https://science.nrao.edu/vlass/commensal-surveys

Tracy et al. 2016 , Poliensky et al. 2016 & Peters et al. 2021

The VLASS Commensal Sky Survey (VCSS)



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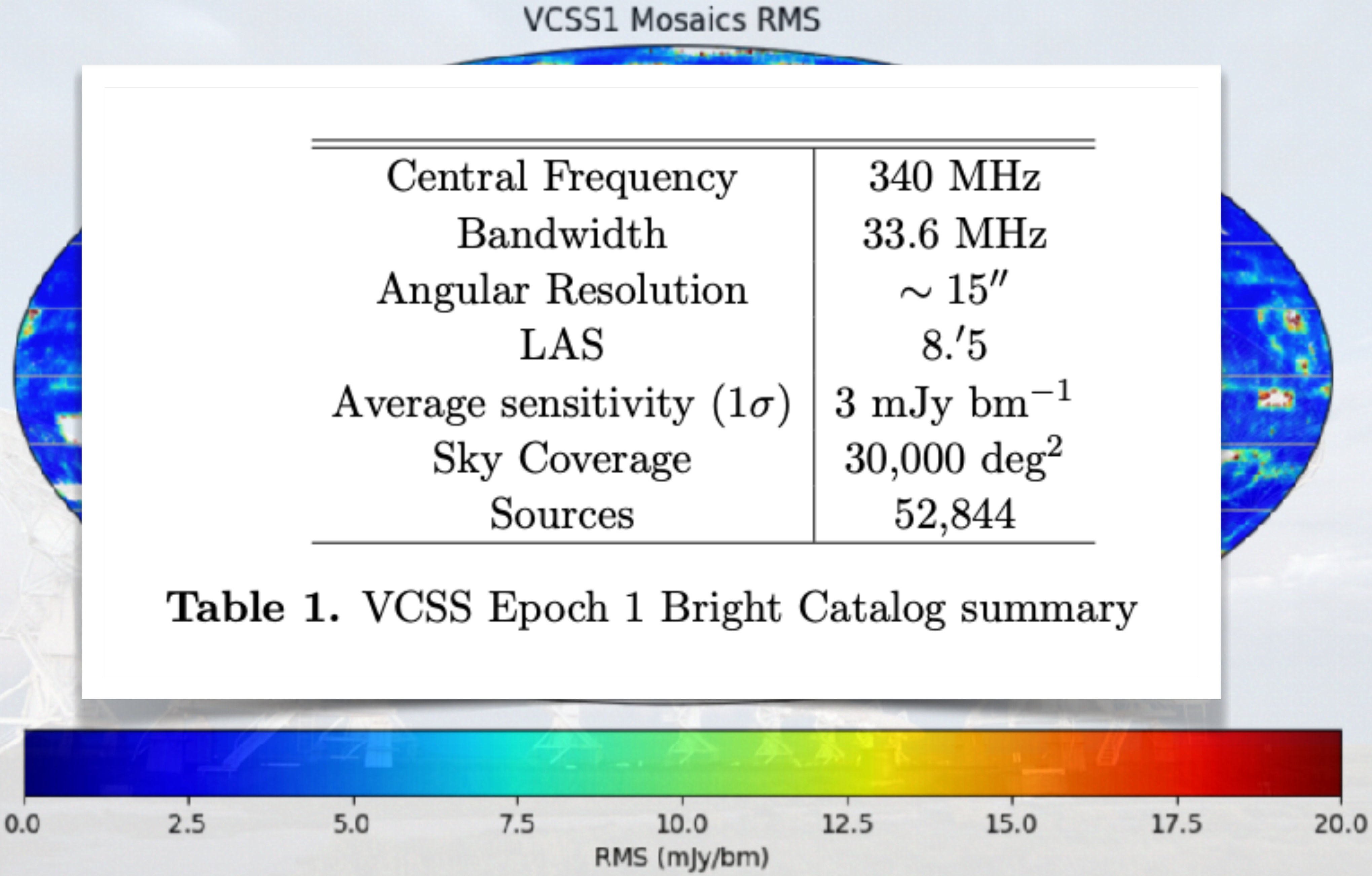


Central Frequency	340 MHz
Bandwidth	33.6 MHz
Angular Resolution	$\sim 15''$
LAS	$8.'5$
Average sensitivity (1σ)	3 mJy bm^{-1}
Sky Coverage	30,000 deg^2
Sources	52,844

Table 1. VCSS Epoch 1 Bright Catalog summary

Instrument: -> VLA Low-band Ionosphere and Transient Experiment (VLITE)

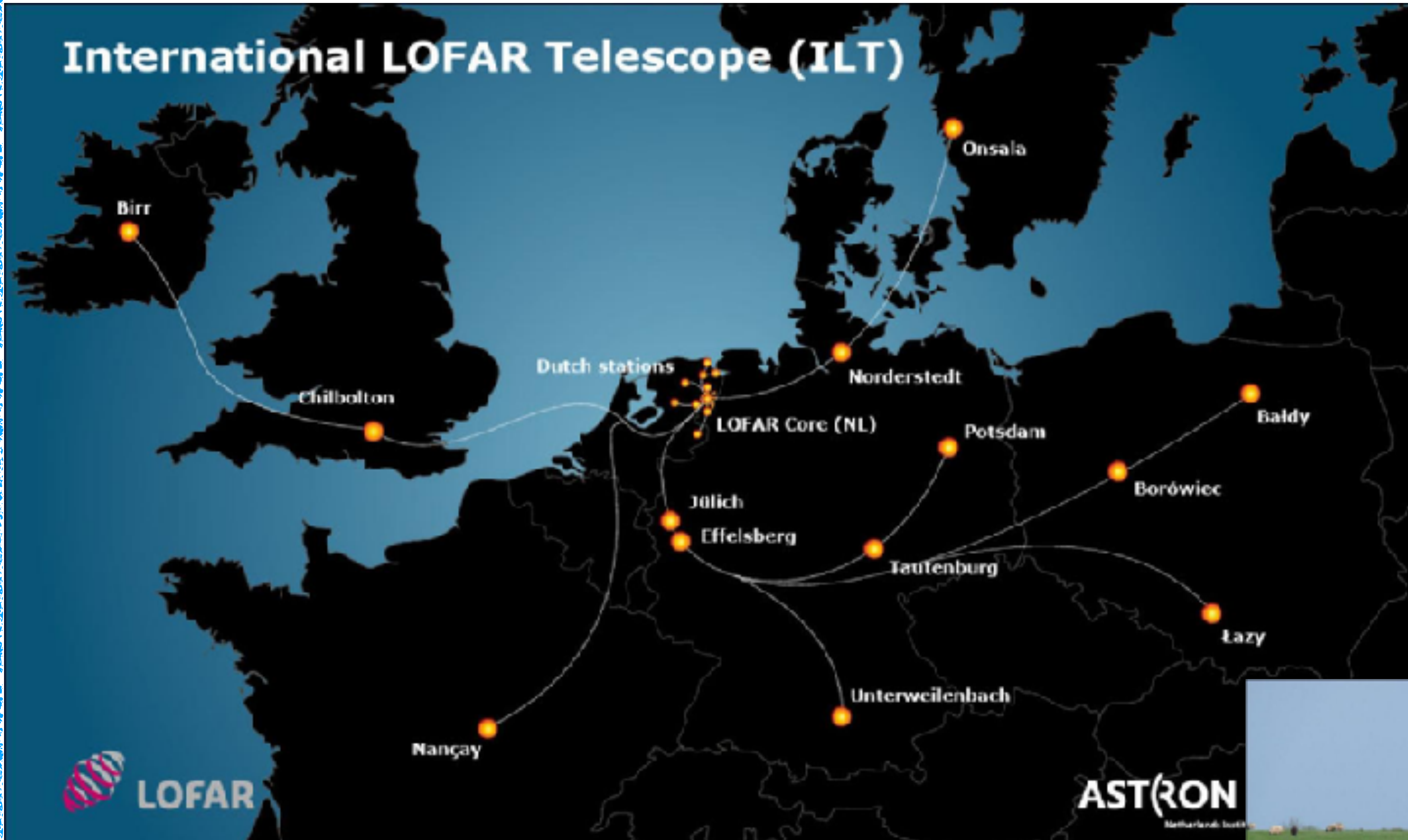
https://science.nrao.edu/vlass/commensal-surveys

Tracy et al. 2016 , Poliensky et al. 2016 & Peters et al. 2021

LOFAR LBA Sky Survey (LoLSS)

F. de Gasperin et al. 2021, A&A 648, A104

https://lofar-surveys.org/lba.html



LOFAR Low- Band Antenna

LOFAR LBA Sky Survey (LoLSS)

F. de Gasperin et al. 2021, A&A 648, A104

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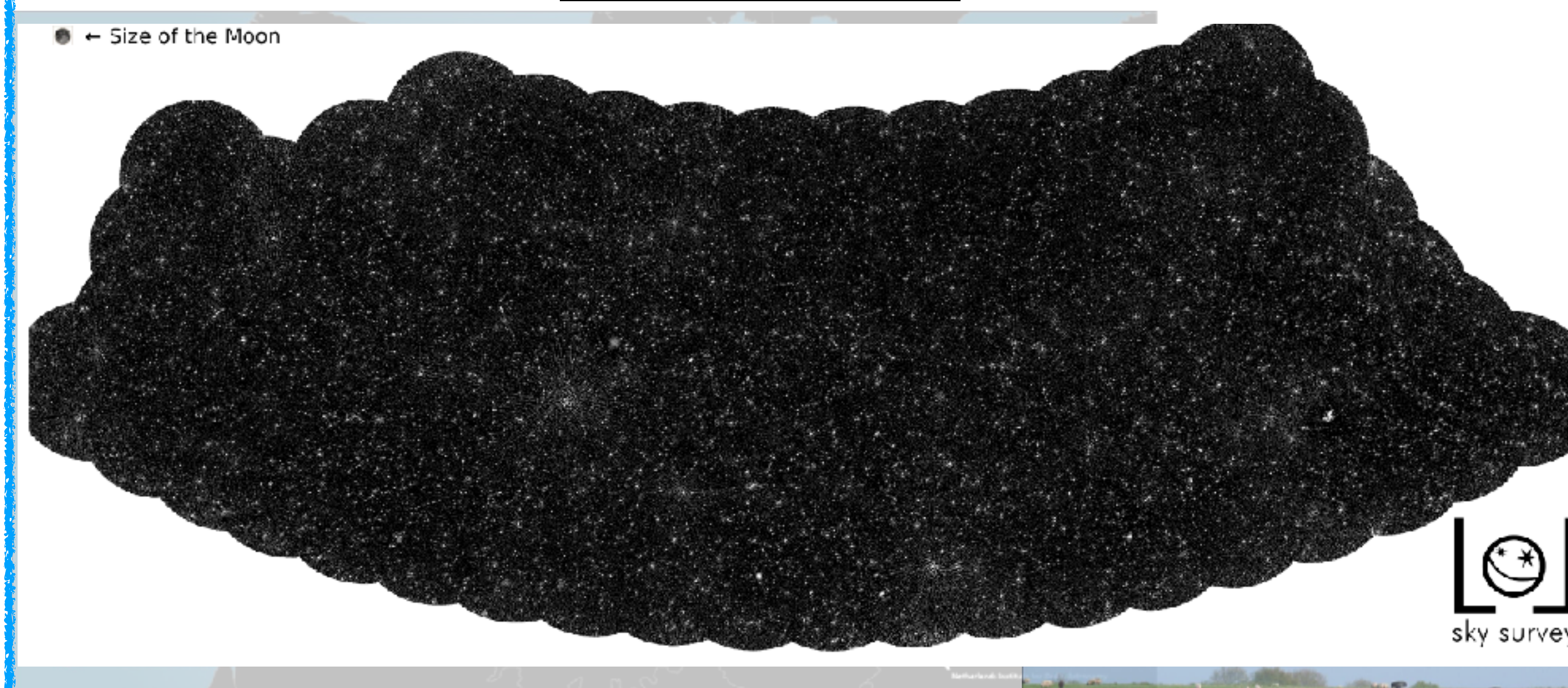

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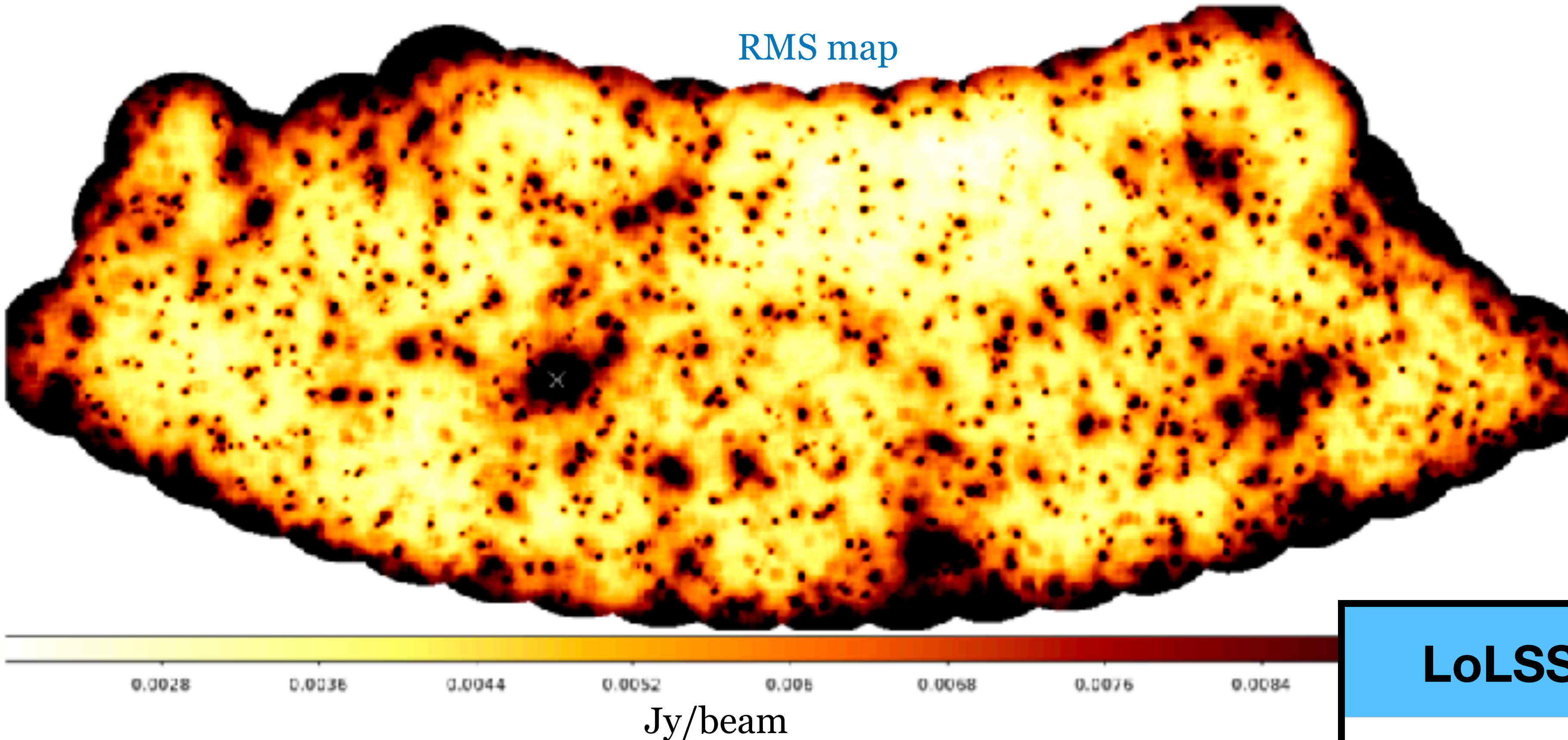


https://lofar-surveys.org/lba.html

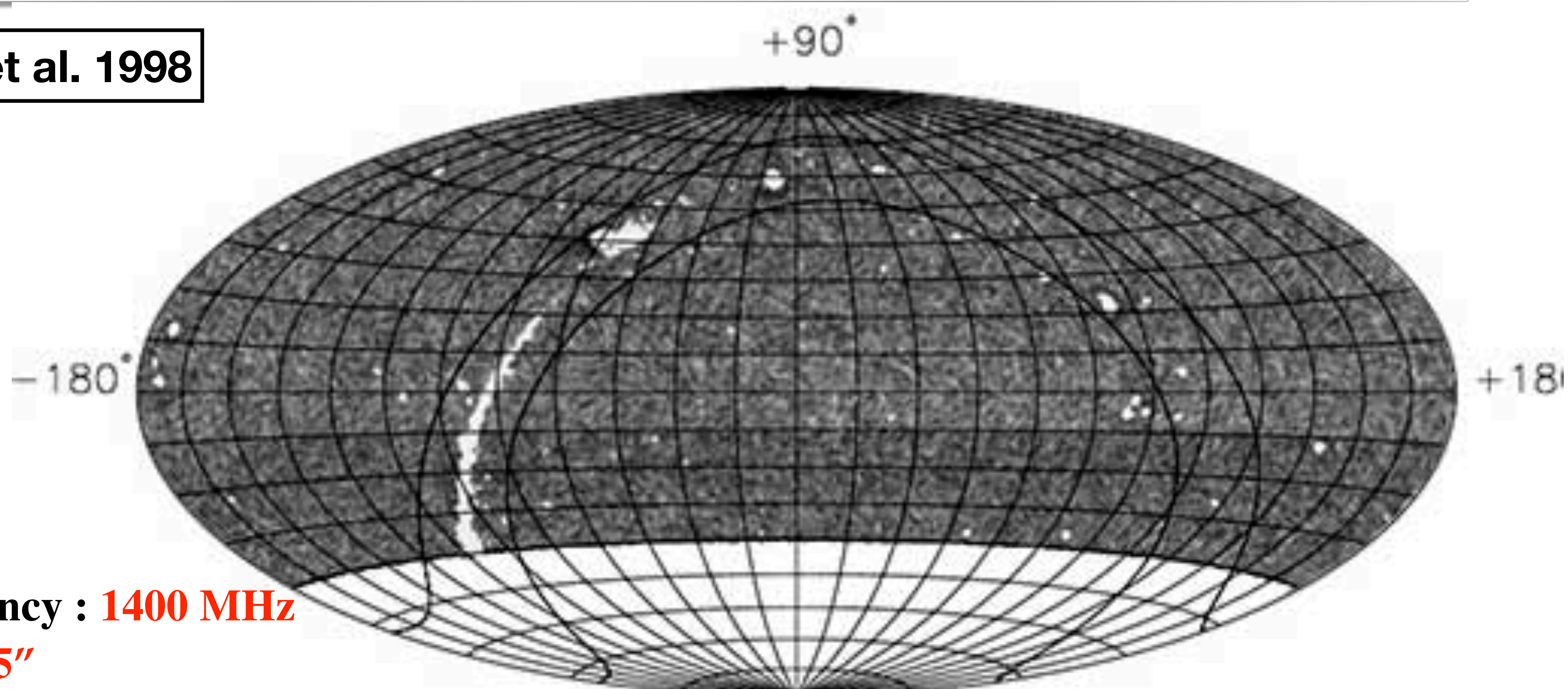
LoLSS preliminary data release	
Central frequency	54 MHz
Bandwidth	42 - 66 MHz
Angular resolution	47″
Average Sensitivity	5 mJy beam^{-1}
Sky coverage	740 deg^2
Sources	25247

1st such low frequency survey at 54 MHz with good sensitivity and resolution!

First high resolution view of wide sky at 54 MHz

NVSS

Condon et al. 1998



−90°

Survey frequency : 1400 MHz
Resolution : 45″
RMS : 0.45 mJy/beam
Sources : 1773484

Observations from 1993 to 1996
Data release ~ 1998

I

The VLASS Commensal Sky Survey (VCSS)
340 MHz

✓Confirming S-alpha relation at metre-wavelength using higher source statistics.
✓Extending to lower flux density levels.
✓Less affected by source curvature issue.

$$\alpha_{340}^{1400}$$

Flux density range ~ 0.2 < S < 2 Jy

NVSS
1400 MHz

✓Establishing S-alpha relation at Decametres for the first time.

$$\alpha_{54}^{1400}$$

II

LOFAR LBA Sky Survey (LoLSS)
54 MHz

Dabhade & Gopal-Krishna 2023, A&A 675, L3

VCSS - NVSS

Range/bin (0)	Range of $S_{340\,\mathrm{MHz}}$ (1)	$S_{340\,\mathrm{MHz}}$(median) (2)	Number (3)	α_{340}^{1400}(median) (4)	ND (5)
All sources	200.0–135 306 mJy	461	42 890	−0.811 ± 0.003	1272
R1	200.0–235.7 mJy	218	3574	(−0.765) −0.763 (−0.760)	45
R2	235.7–269.9 mJy	252	3575	(−0.782) −0.778 (−0.775)	55
R3	269.9–307.5 mJy	288	3573	(−0.792) −0.787 (−0.782)	64
R4	307.5–350.0 mJy	328	3574	(−0.795) −0.791 (−0.786)	59
R5	350.0–400.5 mJy	374	3575	(−0.795) −0.789 (−0.783)	85
R6	400.5–461.1 mJy	430	3573	(−0.808) −0.801 (−0.794)	107
R7	461.1–540.1 mJy	498	3574	(−0.808) −0.800 (−0.792)	119
R8	540.1–648.3 mJy	590	3575	(−0.821) −0.815 (−0.808)	125
R9	648.3–803.2 mJy	716	3574	(−0.823) −0.814 (−0.806)	132
R10	803.2–1071.4 mJy	921	3574	(−0.834) −0.825 (−0.816)	148
R11	1071.4–1676.3 mJy	1299	3575	(−0.850) −0.840 (−0.828)	167
R12	1676.3–135 306 mJy	2547	3574	(−0.862) −0.851 (−0.838)	166

α_{340}^{1400}

Dabhade & Gopal-Krishna 2023, A&A 675, L3

LoLSS - NVSS

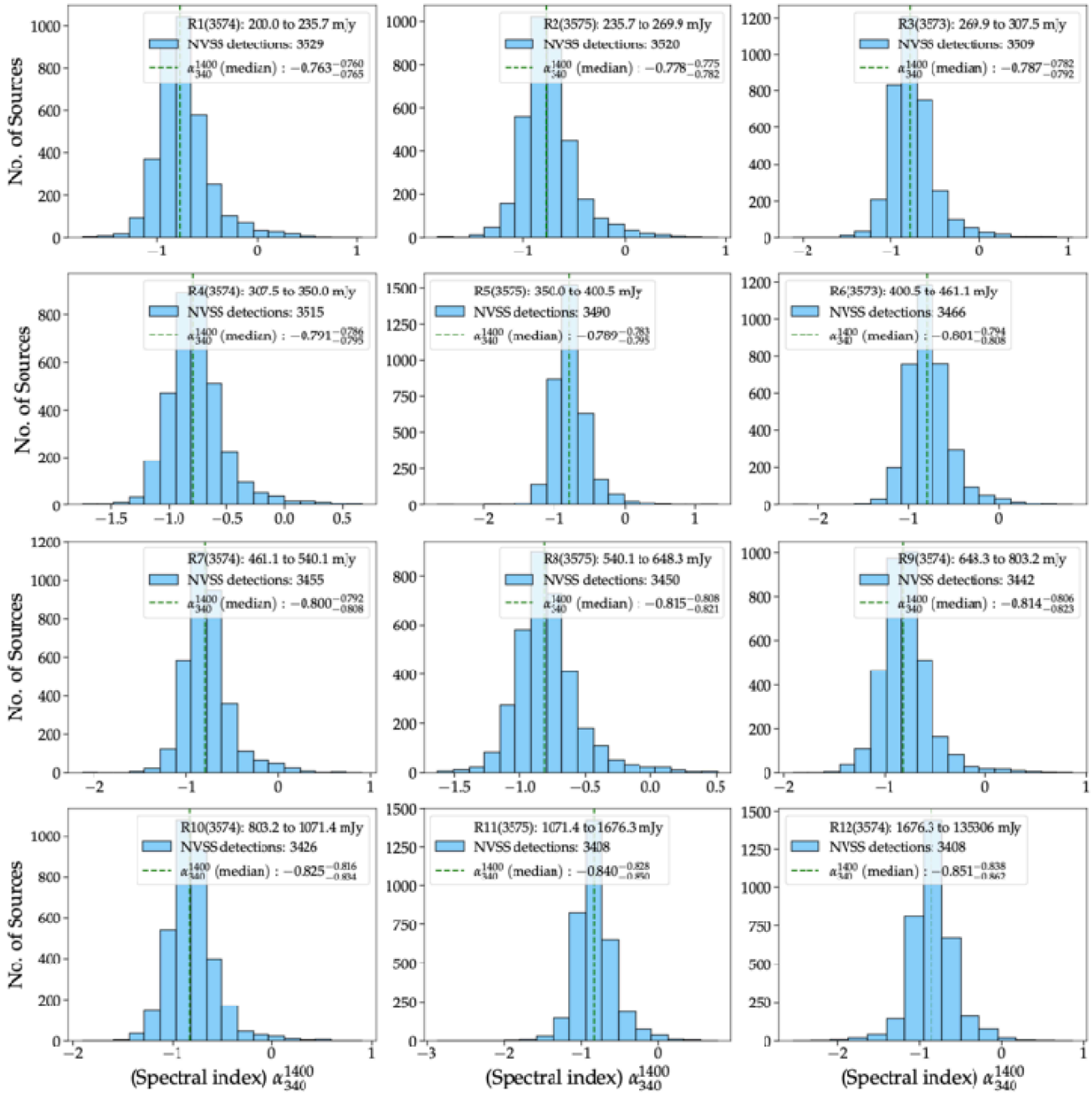
Range/bin (0)	Range of $S_{54\,\mathrm{MHz}}$ (1)	$S_{54\,\mathrm{MHz}}$(median) (2)	Number (3)	α_{54}^{1400}(median) (4)	ND (5)	VSS (6)
All sources	200–129 710 mJy	439	7746	−0.860 ± 0.004	1629	699
R1	200.0–235.0 mJy	218	969	−0.840 ± 0.008	192	5
R2	235.0–278.4 mJy	255	968	−0.852 ± 0.008	193	10
R3	278.4–343.7 mJy	307	968	−0.857 ± 0.009	204	12
R4	343.7–438.9 mJy	386	968	−0.857 ± 0.009	210	18
R5	438.9–593.7 mJy	501	968	−0.860 ± 0.010	187	10
R6	593.7–867.0 mJy	706	968	−0.872 ± 0.011	222	200
R7	867.0–1554.0 mJy	1116	968	−0.862 ± 0.013	219	229
R8	1554–129 710 mJy	2507	969	−0.870 ± 0.018	202	215

α_{54}^{1400}

Flux density range ~ 0.2 < S < 2 Jy →

Dominated by intrinsically powerful, distant radio sources of synchrotron emission, having a median redshift of ~1 (e.g., Condon 1989).

Dabhade & Gopal-Krishna 2023, A&A 675, L3



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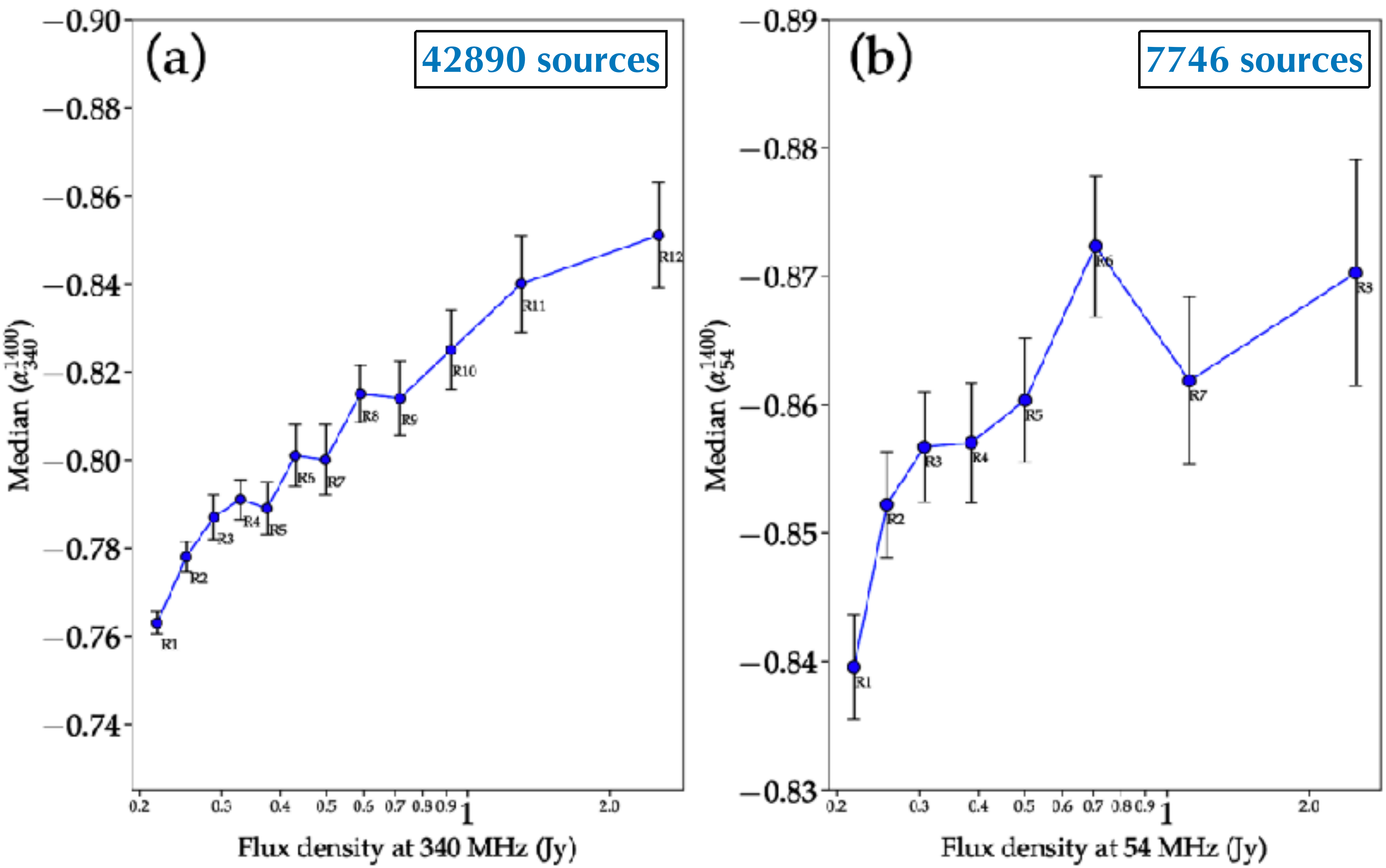
Astronomy & Astrophysics

Letter to the Editor

The spectral index-flux density relation for extragalactic radio sources selected at metre and decametre wavelengths

Pratik Dabhade[1,2] and Gopal-Krishna[3]



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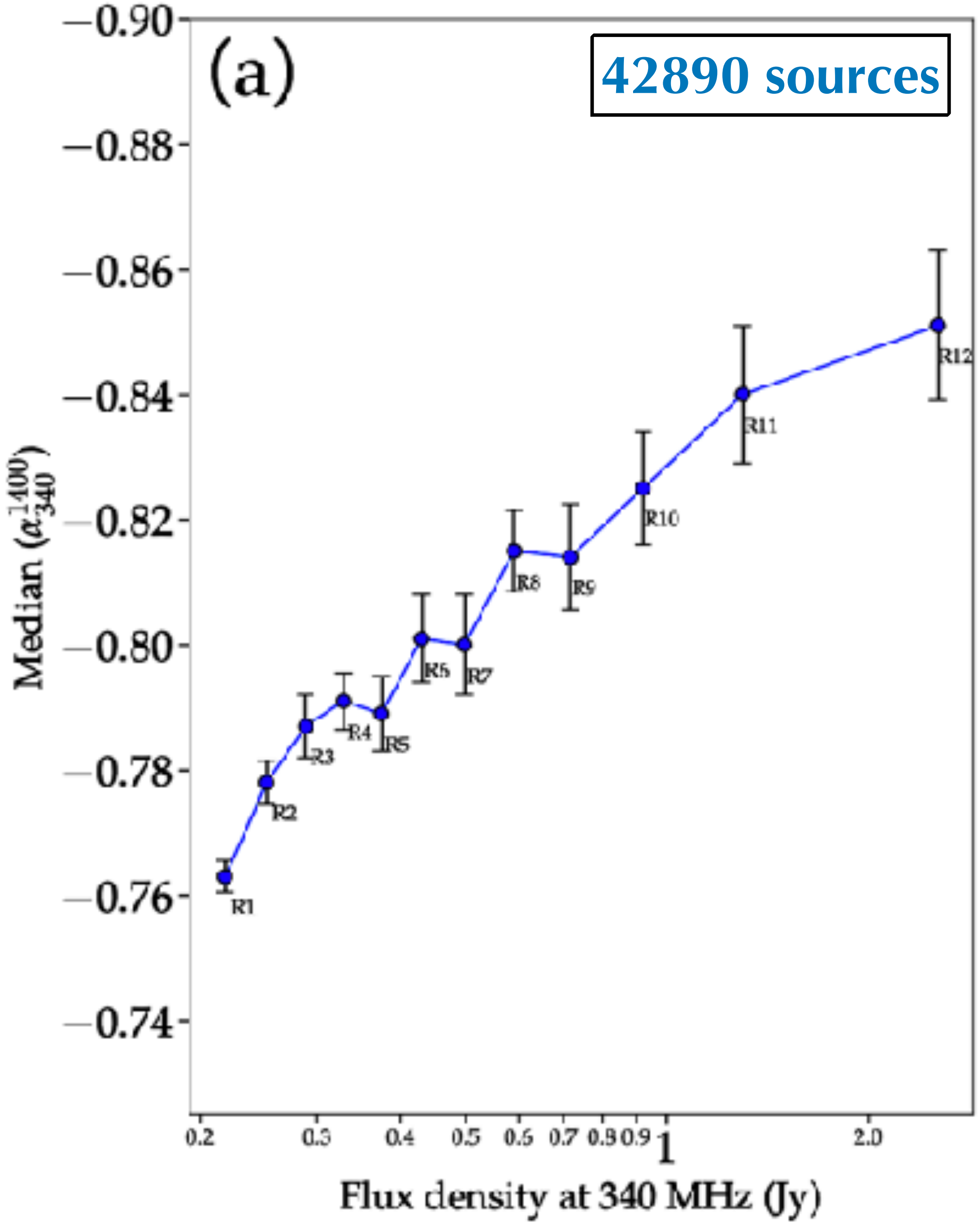

$$\alpha_{340}^{1400}$$

- ✓ Demonstrates that median spectral index (α_{median}) becomes progressively flatter towards decreasing flux densities below $S_{340\ MHz}$ ~1–2 Jy, where α_{median} has been known to attain its steepest value.
- ✓ This is in accord with the trend initially reported in the 1980s (Gopal-Krishna & Steppe 1982; Steppe & Gopal-Krishna 1984) and also seen in some recent studies (Tiwari 2019; de Gasperin et al. 2018) using the TGSS ADR1 survey at 147 MHz.

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Astronomy & Astrophysics

LETTER TO THE EDITOR

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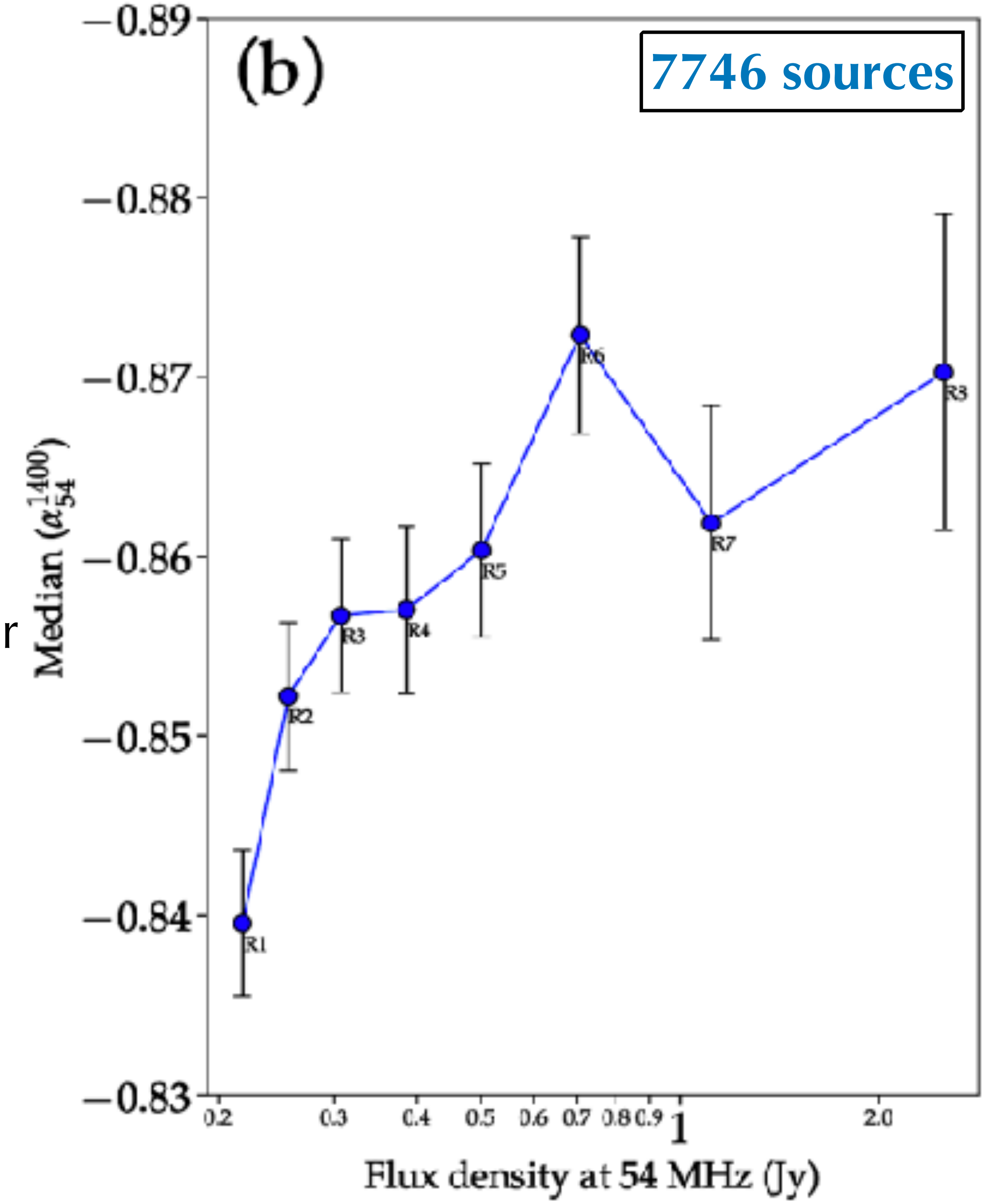
Pratik Dabhade[1,2] and Gopal-Krishna[3]

$$\alpha_{54}^{1400}$$

- ✓ Determination of α_{median}–S_{54} relation for extragalactic sources selected at decametre wavelengths.
- ✓ Flattening (*although milder*) of spectral index @ lower flux densities observed.



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Letter to the Editor

Astronomy & Astrophysics

The spectral index-flux density relation for extragalactic radio sources selected at metre and decametre wavelengths

α_{54}^{1400}

Pratik Dabhade[1,2] and Gopal-Krishna[3]

- Non-detections
- Very steep spectrum sources (VSS)

-Baldwin & Scott 1973
-Slingo 1974
-Roland et al. 1976
-Bagchi & Kapahi 1994
- de Gasperin et al. 2017
-Botteon et al. 2020

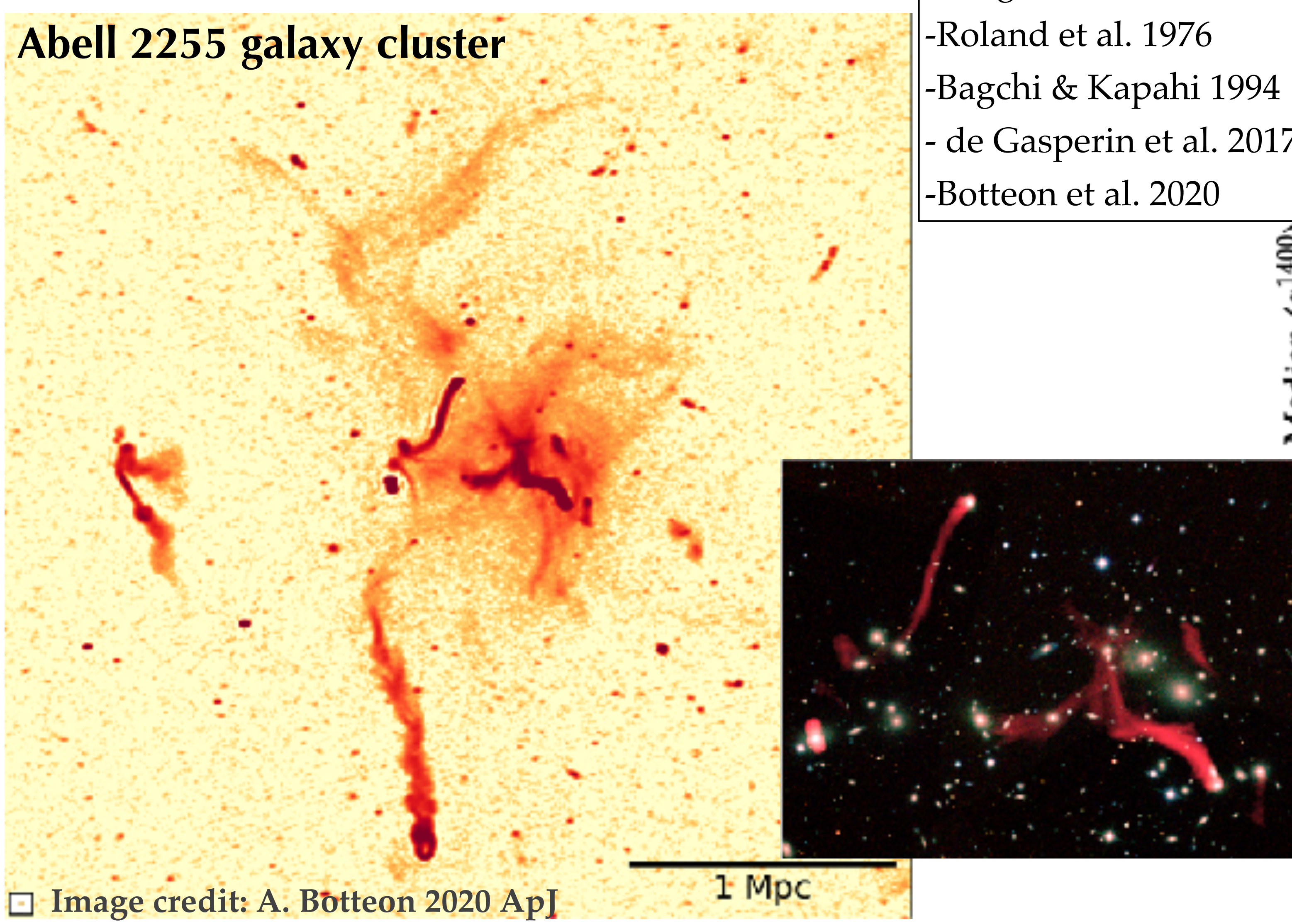
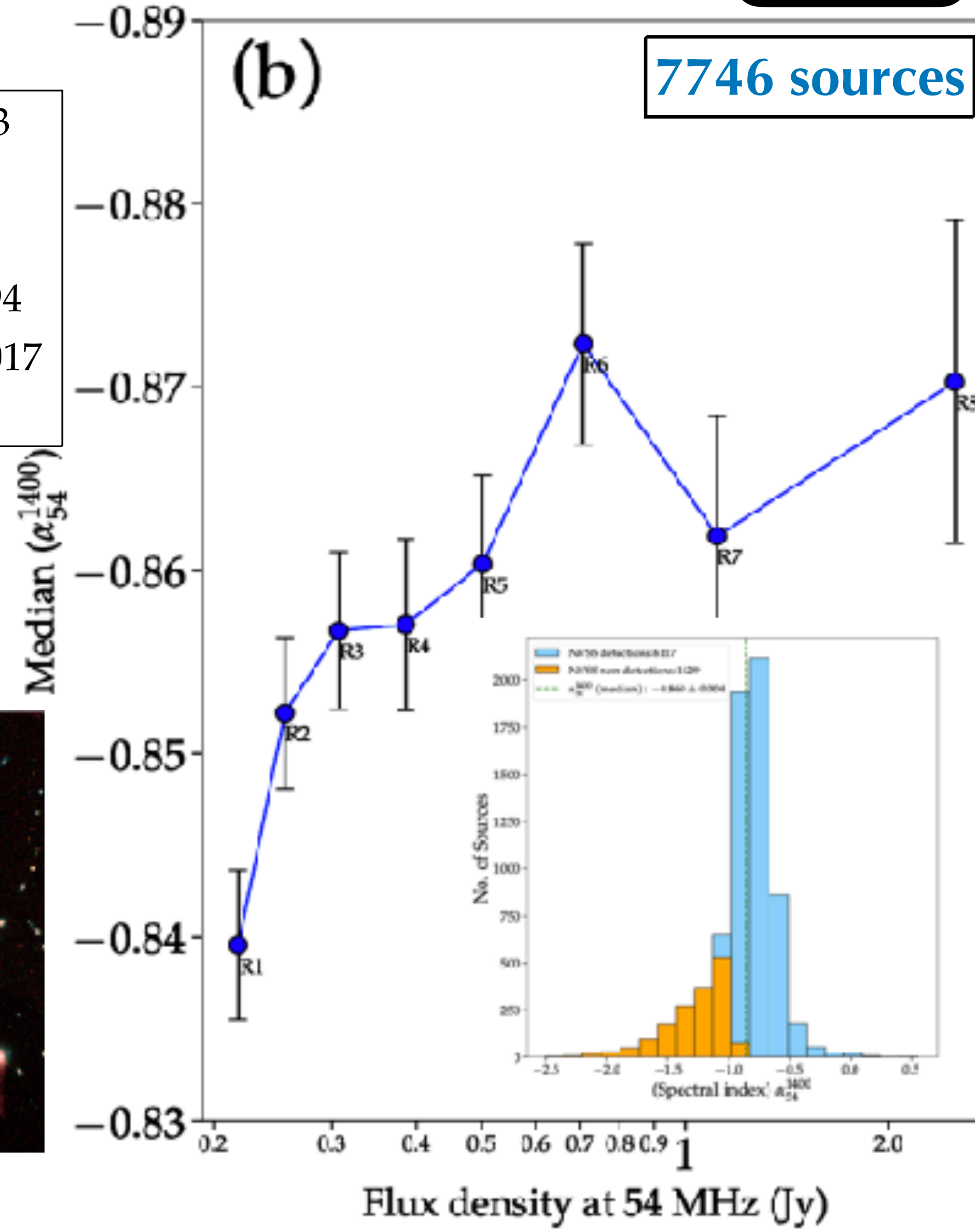
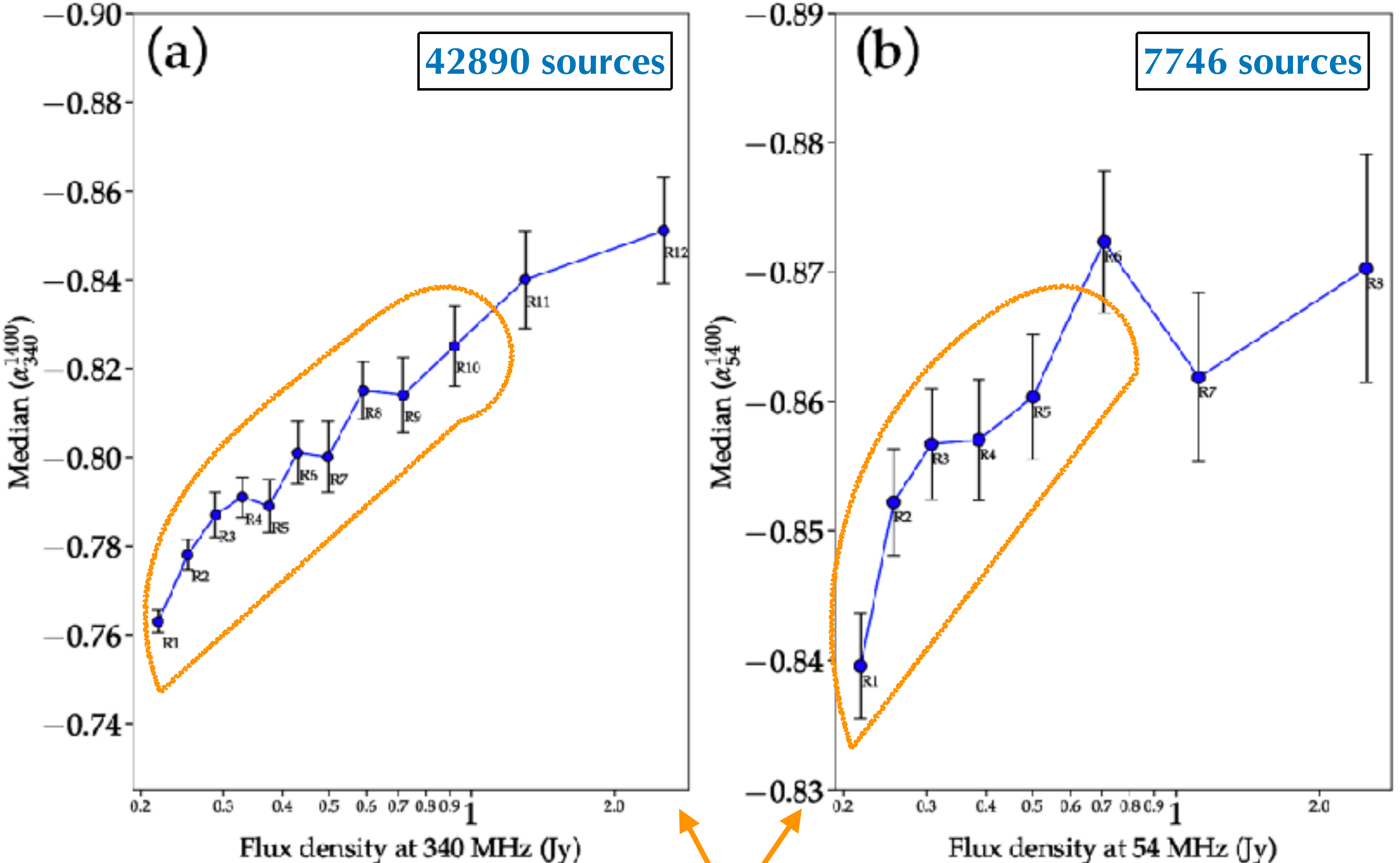


Image credit: A. Botteon 2020 ApJ



Dabhade & Gopal-Krishna 2023, A&A 675, L3



~ Flatter spectral index source population ?

- Star forming galaxies
- Compact radio sources
- Core dominated radio galaxies

Observational indications from the flattening of alpha (med) at lower flux densities suggests a growing presence of lower power radio galaxies, younger (shorter-lived?) radio galaxies and starburst galaxies.

Supported by observations of Calistro Rivera et al. 2017, de Gasperin et al. 2018a, Williams et al. 2021.

Summary & Future scope

- ◉ Determined ‘α_{median} - flux density’ for extragalactic radio sources @ metre wavelengths with significantly better statistics.
- ◉ Established ‘α_{median} - flux density’ for extragalactic radio sources @ ~ decametre wavelengths.
- ◉ Confirmed spectral flattening at lower flux densities.

- ◉ Determine ‘α_{median} - flux density’ relation using complete redshift information.
- ◉ Sub-population studies (identifying AGNs, SFGs etc)
- ◉ More sensitive wide-sky area low frequency surveys
  - ▸ LoLSS-DR3
  - ▸ 14–30 MHz LOFAR Decametre Sky Survey (LoDeSS)
  - ▸ GLEAM-X

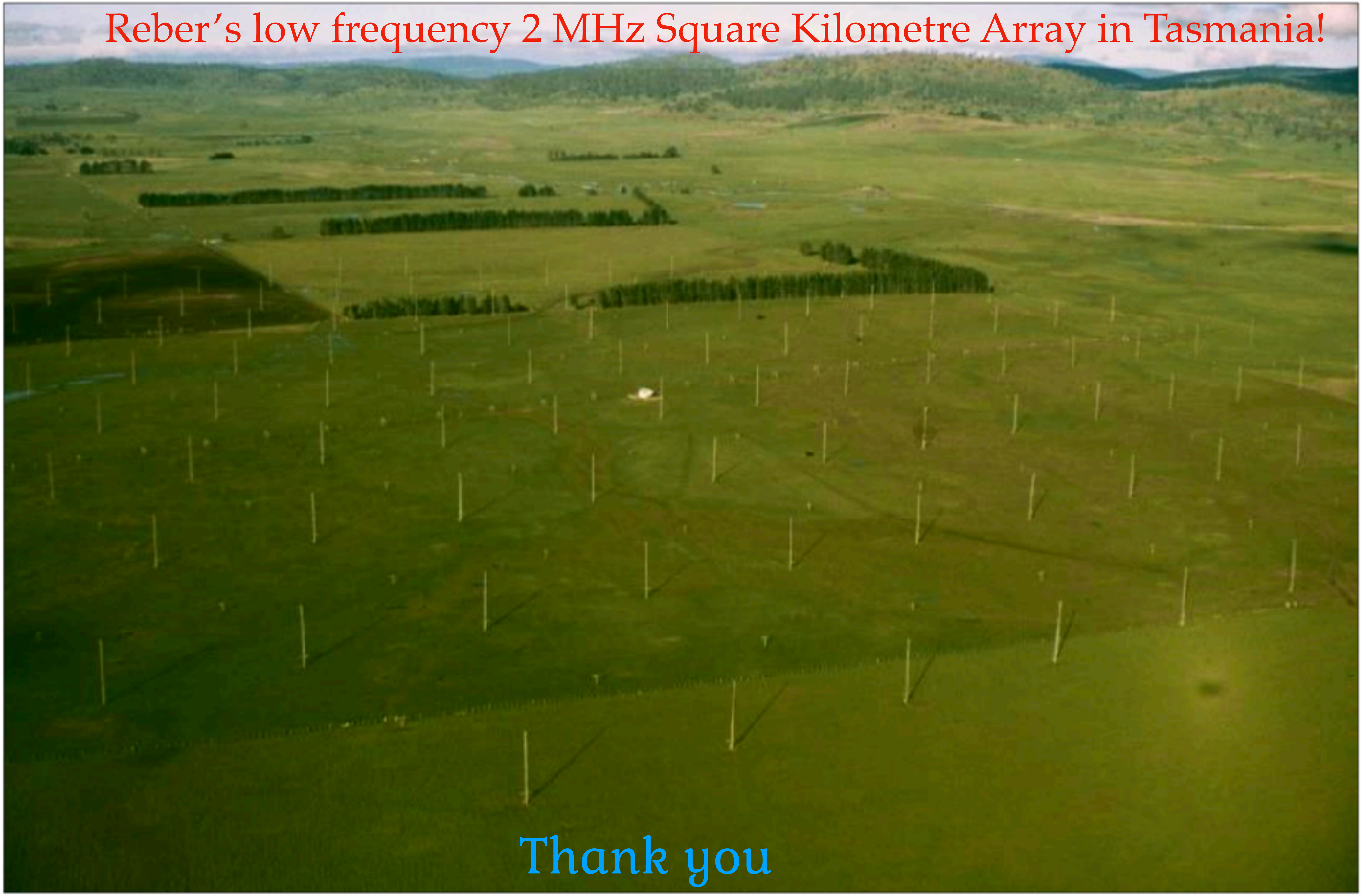


Figure 6: An aerial photograph taken during an afternoon in 1965. The original colour slide was processed in December 1965; the shadow lengths and azimuths make the likely date of the photograph early October (more likely, given the lush appearance of the scene) or early March. The photograph is likely to have been taken by Vern Reid (courtesy: Estate of Grote Reber).

Credit: George, Orchiston, & Wielebinski 2017, Journal of Astronomical History and Heritage